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OPERATIONS RESEARCH APPLICATIONS IN SUPPORT PLANNING

FOR MANNED SPACE FLIGHT

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ABSTRACT 14155

Manned space flight offers significant opportunities for the application of Operations Research to problems of support system planning. Launch base planning comprises traditional problems such as the development of maintenance policies including possible preventive maintenance, and new problems such as countdown planning where mathematical models can account for operational factors and be used to help improve launch effectiveness. Support planning for missions in space requires the resolution of problems in decision making, spare parts kit planning, optimal timing of activities, and other problems requiring an operational-mathematical approach. This paper explores applications of Operations Research to the planning of support aspects of the Apollo mission and system, and against this background, generalizes to the potential roles of Operations Research in planning for the support of manned space flight.

AUTHOR

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INTRODUCTION

Manned space flight offers significant opportunities for the application of Operations Research to problems of support system planning. One of our purposes during this meeting is to demonstrate similarities between fields of OR application and to explore areas of mutual interest to persons operating in diverse fields. I believe that the field of support planning for manned space flight is appropriate for discussion in this context. Moreover, it is an area where, I believe, we as a professional body can make useful and significant contributions to both our national goals in space and general scientific exploration of space.

Manned space flight begins at the launch facility, which like other facilities, comprises systems of men and equipment which must be planned, designed, and operated so as to accomplish their objectives in an efficient and economical manner. These are familiar words and they are reflected in familiar problems for the operations researcher engaged in the planning of support systems for manned space flight. I am going to discuss several of these problem areas, and as I have been asked to do, I will emphasize the broad, policy aspects of these areas. But because some of these problems are familiar, I will be purposely brief here so as to have sufficient time to discuss some of the less familiar problems associated with planning for effectiveness of operations and for survival in space--for this is the primary mission of a support system in a space environment.

The problems that I will present have arisen during our study, at RAND, of Apollo support operations. I believe the extension of these problems to other manned space missions will be evident as will be the present and future roles of Operations Research in planning for these missions.

SUPPORT OF PRELAUNCH OPERATIONS

Any study of support operations must start somewhere. Let's assume that we can start with a sequence of physically required prelaunch operations that begins with the arrival of parts at the launch base and culminates in the launch, and a broadly stated launch objective. This broad objective will reflect the policy, goals, and operational philosophy of the organization that will launch the space vehicle. One such objective is this:

> The general objective of prelaunch operations is the preparation of the space vehicle for launch in a safe, economical, and efficient manner and the launching of the space vehicle into a ready range, within a specified time window and in a condition that is compatible with its mission requirements.

The primary requirement of this objective is that the space vehicle be prepared for launch. Clearly, this preparation must be conducted in a manner that presents low hazards to the ground crew, but it is recognized in this objective that a tradeoff could exist between safety and the objective of launching in a timely manner, i.e., into a launch window, or between safety and efficiency, for example.

The economy and efficiency implied by this objective are of the broadest nature; they refer to the total costs in manpower, equipment, dollars, time, and whatever other resources are consumed in preparation. Implied by this objective, then, is the requirement to plan the sequence of activities so that the launch objective is met for the lowest feasible cost consistent with this launch objective. Yet, to obtain these goals alone is not the objective, but to obtain these, while also meeting the other goals, such as safety.

In summary, this objective is, at the same time, a synthesis of numerous goals and a framework for numerous predesign studies and tradeoffs. Moreover, this overall objective implies objectives for each of the activities in the prelaunch sequence.

This broad launch objective must now be projected into a sequence of objectives for each major part of the system--the ground system, the launch range and the space vehicle--for each of the physically necessary steps--the mating, preparing, and launching activities. This is in part an operations research problem, for it requires the logical structuring of a set of objectives, each of which contributes, according to a series-parallel arrangement, to the overall launch objective.

These objectives must be consistent with the philosophy of the launching organization--but, at the same time, they will help shape that organization's philosophy, to the extent that new ideas embodied in the objectives are adopted. And, this consistency is crucial. From these objectives one can develop measures of effectiveness upon which subsequent analytical efforts will be based. If the objectives are not consistent with the organization's prior--or adopted--philosophy, then the results of studies based on these objectives will potentially be discordant with the views of those who must take action based on the study results.

Once the objectives and measures are known, analytical approaches can be made to the problems inherent to launch base planning. Among such problems are these:

The quantity and location of the various facilities for preparation and launch. A launch base, such as the one being prepared to handle the Apollo, will be used for numerous space programs. If one were involved in the planning of such a base, then presumably he would know the rate at which space vehicles must flow through the facilities to meet the various launch demands. (Selection of a preferred rate is also an OR-type problem.) Classical industrial engineering techniques involving flow diagrams and operation time estimates, and considerations of engineering economics can then be coupled with our methods for dealing with stochastic processes, e.g., queuing theory and Markov chain theory, to provide planning aids for questions of how many are needed of various facilities.

The characteristics of prelaunch maintenance. Here the usual problems of planning for economic maintenance including possible planned replacement must be resolved. Fortunately, a wealth of good work has already been done in this area so that here too we are on familiar ground. The unfamiliar aspects of these problems revolve largely about the characteristics of the space vehicle: What are the failure and wear-out characteristics? How much operation is adequate for burn-in and passage through the infant mortality stage? Here too, however, we cannot neglect the policies and philosophy of the launching organization. Chances are that they will have been in the vehicle preparation and launching business for quite some time, and will have strong views based on experience. Their attitudes will require conscious attention, either to accept into the study or to adapt or modify as a consciously considered purpose of the study.

Countdown planning for launch effectiveness. This is the last prelaunch topic that I want to discuss, and it is one in which OR can and is moving into new areas of application. Physical requirements such as pressure and voltage levels and guidance system alignment dominate present planning for prelaunch and countdown activities; this planning is typically done by engineering staffs from a predominately "hardware" point of view. Operational factors play, however, a significant role in determining the success of the countdown activities. By this, I mean that operational factors such as equipment failures, human errors, testing errors, and range problems have a significant impact on the success of the launch attempt; their impact is potentially as important to the launch as are such "hardware" factors as guidance system accuracy and ground-to-vehicle telemetry compatibility. An OR study for countdown planning should be concerned with the problem of adequately accounting for these operational factors when planning the countdown activities.

During our RAND work for NASA we have taken several approaches to developing a model of a countdown that can be used for planning and evaluation purposes. One approach combines linear programming with a general Markov process and a computational search routine, while another utilizes a Monte Carlo model to describe a countdown in terms of its stochastic and deterministic properties. These models necessarily combine engineering with operational, probabilistic model building--but that is a combination with which many operations researchers have worked for a long time. So that, while the application is new, the frame of reference is not.

So much for the prelaunch study areas where operations research can be applied to support system planning for manned space flight. I believe it is fair to conclude this part of my talk by observing that: to an OR practitioner, the operation of a launch facility for going to the moon, or further, isn't really much different than the operation of many other systems on earth.

SUPPORT OF IN-SPACE OPERATIONS

Any division of activities between primary mission operations and support operations must contain a certain degree of arbitrariness. My definition of support operations for in-space missions will illustrate this point. Operations that support space missions are those that provide the supplementary capability, i.e., that in excess of the mission-oriented use of the basic prime equipment, to survive and achieve a successful mission. Illustrative of the activities and problems in this category are maintenance, timing of checkout and maintenance operations, the checkout operations themselves, and, by association, the formal process of decision-making based on checkout-obtained data. Support planning also encompasses such problems as spare parts kit planning and optimal patterns of redundancy. In keeping with the purpose of my talk, I will explore the application of operations research to the solution of planning problems in these areas.

Let's start with the most familiar area--that of spare parts kit planning. Because of its similarity to the classical Flyaway Kit Problem for aircraft spares planning we have called this the Blastaway Kit Problem. The problem is this: the weight, and perhaps the volume, that can be allocated to spare parts to be carried aboard a spacecraft are limited. Due to this limitation all the spares that would be desirable cannot be carried. Therefore, spare part weight must be allocated among the alternative spares according to some optimizing policy. The problem is that of generating this optimizing policy or decision rule.

Organizational and operational philosophies enter into this problem in the very beginning; an objective for the spare parts kit must be selected. This requires a selection from such objectives as:

- To maximize the probability that no failures will occur for which a spare part is not available, or
- To maximize the expected number of potential failures for which spare parts are available.

Once an objective, reflecting the organizational philosophy, has been selected an objective function can be developed and the problem resolved. The mathematics of operations research are useful for obtaining a solution.

Developing a maintenance concept for use in a spacecraft, or for use on the lunar surface, for example, is also a problem with many elements that are familiar to the operations researcher. We have done this for many earth-borne systems. But, there are new twists to this problem in a space environment. Weight and volume are exceptionally costly and needed for prime mission equipment. A maintenance working position requires body constraints. A prolonged stay in space and operations in deep space require a degree of self-sufficiency far in excess of that encountered on earth--it's a long way to the nearest depot. Moreover, man's capabilities after prolonged exposure to weightlessness and space-mission stresses are still matters of speculation. Hence, in our studies we must find meaningful and not unnecessarily conservative ways to hedge against these uncertainties, live within the constraints, and meet the mission requirements.

Another problem that has received attention in the space support planning area is that of mission effectiveness simulation models. As is typical for large systems, the system itself is an expensive and therefore unlikely mechanism for determining or evaluating new plans or procedures. A model of the system is much more amenable to manipulation and modification. For manned space missions, analytical models for overall mission effectiveness estimation are of limited utility. A spacecraft has more modes of operation and significant parameters, and a mission with more possible paths than analytical techniques can feasibly handle. Hence, we employ Monte Carlo simulation techniques. The techniques employed and the problems inherent to their application are similar to those in many other areas of system simulation; only the problem context and variables employed are significantly different. Being a powerful tool, we find it useful for difficult problems. For example, it can be used to evaluate alternative maintenance policies and alternative decision policies. It is also useful for initial sensitivity tests of the dependence of mission success to such planning factors as spare parts allotments, number of back-up modes, and test capability.

Some interesting analytical problems arise in planning the timing of checkout and maintenance activities. The timing of checkout activities arises in this context. During the course of a manned space mission, changes in the mission profile must be made. For example, the Apollo spacecraft must be inserted into lunar orbit from a translunar coast. This operation requires that certain spacecraft equipments be in operating conditions. If they are not, the results could either be undesirable or catastrophic. The checkout of these systems must be timed so that any necessary maintenance can be performed (in a time given by a probability distribution) but not so early that unnecessary operating time is accrued by critical systems with the attendant problem of possible post-check failures. This problem is amenable to solution by analytical or computational means familiar to the operations researcher--but first the organizational philosophy must be considered in the selection of an objective function. Do we want to maximize some probability of being ready for the transition at a particular time? Or, do we want to minimize some loss function associated with delaying the mission event (if this can be done). Or, do we want the readiness probability to be greater than some lower bound? Once this issue is resolved, so too can be the problem.

The timing of maintenance activities is the last problem area that I will discuss. And, I will discuss it in the context of the lunar operations phase of the Apollo mission. When the Apollo Lunar Excursion Module lands on the moon, it may contain failed systems. These failures may be known or unknown. Assuming that they are known, for example, leads to the question of when to repair them. An intuitive solution is to start immediately to repair the known failures and if the objective is to be launch ready at all times when on the moon, then the intuitive answer appears correct. If, however, the objective is to maximize the probability of having no failures at the completion of the planned lunar stay, then some initial results point towards the desirability of delaying this maintenance. Here again is an operations research-type problem, amenable to straightforward analysis, and yielding mission success estimates that depend on maintenance timing policies.

Conclusion

In conclusion, we see that there are many problems of support planning for manned space flight that are amenable to solution by operations researchers. Some problems are familiar and require only the extension of other results and studies from numerous areas of OR application. Most of the problems associated with the prelaunch phases of operations are in this category; countdown planning is a notable exception, but only because we haven't tried it for unmanned space vehicles or their military counterparts, i.e., missiles in development phases. To prove that there is really nothing new under the sun--nor on the moon--we found familiar elements in the problems we can solve for in-flight and lunar operations, too. But there the operational context is much different than that of many problems already faced, so that there are new challenges in their solution.

I believe I have demonstrated our usefulness in helping plan for presently conceived space systems. Moreover, I believe that the projection from these problems, resulting from helping plan for Apollo, to problems to be faced in planning other space missions is evident, in that future missions will require support of the same nature. Therefore, support planning problems will exist in future systems, and our operations research talents should be useful for their solution. Moreover, if we follow the pattern of our work in other areas, as we gain experience with this problem area, our effectiveness and involvement will increase.

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